Spatial distribution of a chrysomelid leaf beetle (*Cadmus excrementarius* Suffrian) and potential damage in a *Eucalyptus globulus* subsp. *globulus* plantation

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Summary

The spatial distribution of the chrysomelid beetle *Cadmus excrementarius* Suffrian and associated damage was studied in a 9-mo-old bluegum plantation (*Eucalyptus globulus* subsp. *globulus* Labill.), growing at Rocky Gully in south-western Australia. Adult beetles had a clumped distribution between trees, with beetle numbers being significantly positively correlated with tree size. Beetles were also aggregated within trees, with over 92% present in the upper crown. Defoliation in the upper crown was greater than for the lower crown, and ranged from 0 to 50% of total upper crown foliage, averaging 6.3%. This damage was significantly correlated with tree size and number of beetles. Female beetles consumed significantly more foliage over 48 h (2.9 ± 0.4 cm^2) than the smaller males (0.8 ± 0.1 cm^2). A regression model exploring the relationship between beetle numbers and cumulative foliage consumption was developed. It predicts that 31 or more beetles could completely defoliate the upper crown within 3 mo.

Keywords: plantation; defoliation; spatial distribution; leaf beetle; chrysomelid; *Cadmus excrementarius*; *Eucalyptus globulus* subsp. *globulus*; Australia

Introduction

Chrysomelid leaf beetles are common and serious pests of eucalypt species growing in native forests and plantations throughout Australia (Abbott 1993; Bashford 1993; Neumann 1993; Stone 1993; Elliott *et al.* 1998). Most chrysomelids reported as pests of eucalypts in Australia are in the subfamily Chrysomelinae, which includes the important genera *Chrysophtharta* and *Paropsis*. Species in this group defoliate new leaves and shoots as both adults and larvae, often resulting in the characteristic 'broom-topped' appearance through the removal of the apical crown. Extreme levels of defoliation by chrysomelids can lead to significant reductions in tree height, diameter and volume growth, and potential growth malformation (Candy *et al*. 1992; Elliott *et al*. 1993; Elek 1997).

The chrysomelid subfamily Cryptocephalinae, although not thought to be as economically important as the Chrysomelinae, contains several species that have been recorded as pests of eucalypts in Australia. Of particular concern is the genus *Cadmus*, which is a large group of eucalypt defoliators. Only the adult stage of *Cadmus* species feeds on eucalypts because the larval stage lives on the ground in an ovoid case made of faecal matter, and feeds on litter and leaves (Reid 1999a; dos Anjos *et al*. in press). However, Reid (1999b) recorded *Cadmus aurantiacus* larvae eating young eucalypt seedlings in a south-eastern Australian forest. In Australia, only two species of *Cadmus* have been reported as pests in eucalypt plantations: *C. australis* in Tasmania (Elliott and de Little 1984) and Victoria (M. Matsuki *pers. comm.*); and *C. excrementarius* in south-western Australia (Loch and Floyd 2001).

Cadmus excrementarius is one of the major chrysomelid pests of Tasmanian blue gum, *Eucalyptus globulus* subsp. *globulus* Labill., plantations in south-western Australia (Loch and Floyd 2001). Only scant information on the species is available because the species has only recently been recognised as a serious pest, and only a handful of previous collection records exist (dos Anjos *et al*. in press). *Cadmus excrementarius* is a univoltine species in south-western Australia, with adults emerging in mid-summer and causing damage to new adult and juvenile shoots and leaves of *E. globulus* subsp. *globulus* through until early autumn (dos Anjos *et al*. in press). In this paper, we report on the distribution and abundance of *C. excrementarius* adults within a plantation and quantify the feeding damage caused by adults of this species.

Methods

The *E. globulus* subsp. *globulus* plantation where we studied *C. excrementarius* was situated at Rocky Gully (34°32'S, 117°01'E), where average annual rainfall is about 750 mm. The plantation comprised 1313 ha of trees planted in June–July 2000 on an ex-pasture site. Site preparation prior to planting involved a broad-spray application to reduce weed cover, and ground cultivation to produce parallel mounded planting beds 4 m apart. Following the application of NPK fertilizer, trees were planted at a density of 1000 stems ha^{-1}.

The study was conducted over 11 mo, from late January to early December 2001. Most measurements were made during the peak period of adult activity in February and March, although regular field inspections for adult activity were made throughout the year. A single transect was established in each of five randomly-selected compartments on 8 February 2001, to determine if beetle density and damage exhibited any edge effects. Each transect commenced at the second tree from the edge of the compartment and comprised 14 trees spaced 12 m apart. Transects ran from the northernmost corner to the centre of each compartment. Each tree was divided into an upper and a lower crown, with each stratum corresponding to half the total tree height. The numbers of *C. excrementarius* males and females were counted visually in the upper and lower crowns of each tree. Beetles were sexed on the basis of size, shape of abdomen and tarsal colour: females are larger and have tarsi of a similar colour on all legs, but tarsi 3–5 are darkened in males (dos Anjos *et al.* in press). The level of defoliation in the upper and lower crowns of each tree was visually assessed as a fraction of total foliar area lost through adult *C. excrementarius* feeding. Defoliation was estimated to the nearest 10%, with smaller graduations near 0% (i.e. 0%, 1%, 2%, 5%, 10%). Tree height and stem diameter (20 cm above ground) were measured for all examined trees, and the general status of the apical shoot, where leaves had not yet opened (intact or removed), was recorded.

On 28 February we revisited the same trees and recorded the number of beetles on five selected leaves on which beetles were known to be present. On 4 March we selected 10 trees (2 per transect) of about medial height (102 cm). We removed the top half of each crown and measured the surface areas of all leaves with the aid of a Macintosh® computer scanning system. Leaves were maintained in cool, moist conditions until measured. The consumption of foliage by beetles was also examined on the same date by installing a set of three vials containing water under each of the 14 trees that we inspected along one transect. A leaf was placed in each vial, which was then enclosed in mesh. Either one male, one female, or one male plus one female was introduced into one each of the three vials in each set. The mean leaf area consumed by males, females and pairs was measured after 48 h using the Macintosh computer scanning system. The mean dry weight of male and female beetles ($n = 20$) was also measured.

We looked for correlation between the distance from plantation edge and the tree dimensions, numbers of beetles, sex ratio, and damage levels by applying the Pearson product-moment coefficient of correlation. One-way analysis of variance was used to compare the area of leaves consumed by beetles of each sex. Linear regression was employed to examine the relationship between numbers of beetles and the extent of defoliation in the tree crown.

Results

Tree dimensions

Trees ranged from 33 to 175 cm tall, with a mean and standard error of 102 ± 17 cm ($n = 70$). Measurements for stem diameter at 20 cm above ground ranged from 0.4 to 3.0 cm, with a mean of 1.6 ± 0.1 cm ($n = 70$). There was no relationship between tree height or stem diameter and distance from the edge of the compartment. The mean and standard error of the area of foliage from the upper crown was 3263 ± 331 cm^2 ($n = 10$), and ranged from 1402 cm^2 to 5046 cm^2.

Beetle distribution and abundance

Cadmus excrementarius was present in all plantation compartments sampled but 30% of all trees had no beetles at the time of observation, and 71% of infested trees in all transects had fewer than 10 adults per tree. Numbers of adult beetles per tree ranged from 0 to 59, with a mean and standard error of 6.6 ± 1.3 ($n = 70$) for all transects. There was no correlation between the average number of beetles per tree and distance from the plantation edge.

In occupied trees, 92% of all insects were found in the upper crown. Only 29% of these trees had insects in their lower crown. The mean and standard error of the number of beetles per upper and lower crown was 6.1 ± 1.2 ($n = 70$) and 0.5 ± 0.2 ($n = 70$) respectively. Numbers of beetles in the upper crown were not correlated with distance from compartment edge, but there was a positive correlation with tree height ($r = 0.40$, $P \leq 0.05$, $n = 70$) and tree diameter ($r = 0.56$, $P \leq 0.05$, $n = 70$) (Figs 1a, b).

The mean and standard error of the proportion of female beetles on trees on 8 February was 0.73 ± 0.03 ($n = 49$), producing a sex ratio of 2.7:1. There was no significant relationship between sex ratio and distance from edge of the compartment. Solitary females were found on 26% of the infested trees and, within these trees, on 58% of infested leaves. Solitary males were only found on 4.1% of the infested trees and, within these trees, on 12.6% of infested leaves. Copulating pairs were found on 21% of the infested leaves.

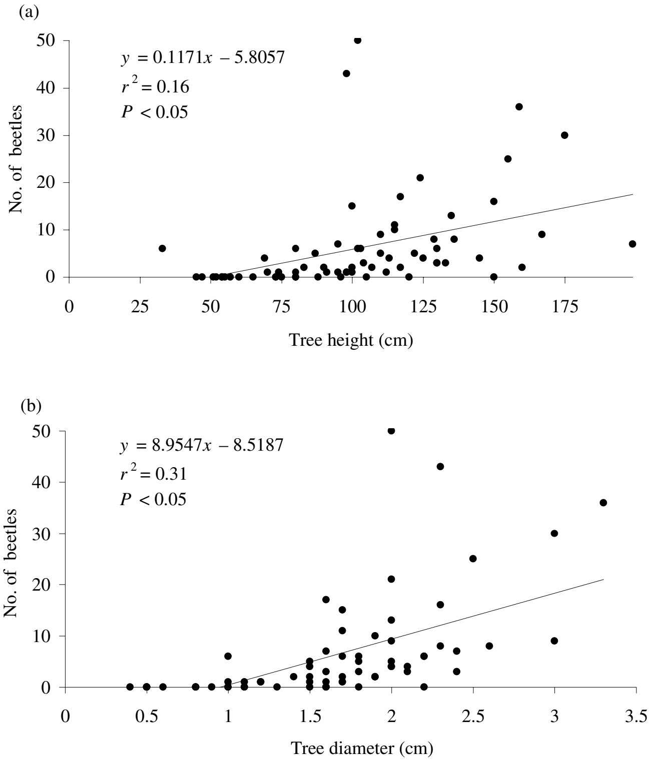

Figure 1. Linear regression between the number of *Cadmus excrementarius* adults observed in the upper crown of 9-mo-old *Eucalyptus globulus* subsp. *globulus* trees versus tree height (a) and diameter (b) on 8 February 2001

Figure 2. Damage caused by adults of *Cadmus excrementarius*: (a) injured leaves, tips and bark; (b) tree defoliation and crown disbudding (see multiple new shoots at apex); and (c) deformation of tree shape (see loss of main shoot and lateral branch growth). The photographs were taken on 8 February, 4 March and 29 April 2001 respectively.

Crown damage

Adults of *C. excrementarius* were observed feeding upon expanded leaves, apical shoots and tender bark (Fig. 2a). This kind of injury led to tree defoliation and crown disbudding (Fig. 2b), which can result in deformed crown shape (Fig. 2c).

All transects had trees with damaged leaves, and more than 75% of all tree crowns had some evidence of loss of foliage caused by this species of beetle. Severe damage, evaluated as defoliation of over 20% of the upper crown plus a killed leading shoot, was recorded on 11.4% of trees, and 50% defoliation to the upper crown was recorded on 1.4% of all trees. Defoliation in the upper crown (mean ± s.e. = 6.3 ± 1.3%, $n = 70$) was greater than in the lower crown, and ranged from 0 to 50% of upper crown foliage. Defoliation in the lower crown ranged from 0 to 5% (mean ± s.e. = 0.5 ± 0.1%, $n = 70$), with no damage recorded on half the trees. No correlation between defoliation level and distance from plantation margin was detected. Defoliation in the upper and lower crowns was significantly positively correlated with stem diameter ($r = 0.56$ and $r = 0.27$ respectively; $P \leq 0.05$, $n = 70$). An index of defoliation was therefore developed that incorporated the degree of defoliation divided by the product of the respective tree height and diameter. Using this index, the extent of defoliation in the upper crown was strongly correlated with numbers of *C. excrementarius* beetles in that part of the crown ($r = 0.84$, $P \leq 0.05$, $n = 70$) (Fig. 3). The defoliation index for the lower crown was also correlated with the respective numbers of beetles ($r = 0.55$, $P \leq 0.05$, $n = 70$).

The area of leaves consumed by *C. excrementarius* beetles differed significantly for males, females and pairs ($F = 9.96$, df =2, $P < 0.001$). The mean and standard error of the area consumed by a female beetle over 48 h was 2.9 ± 0.4 cm^2 ($n = 14$) and by a male was 0.8 ± 0.1 cm^2 ($n = 14$), and by one pair was 3.7 ± 0.5 cm^2 ($n = 14$); the latter is equivalent to the additive effect of the two sexes. The mean and standard error of the dry weight of females and males respectively was 22.6 ± 1.8 and 12.9 ± 1.2 mg ($n = 20$), giving a female:male weight ratio of 1.75:1. The ratio of foliage consumed by females to foliage consumed by males was 3.62:1, suggesting that weight alone does not account for the higher consumption by female beetles.

Considering the average foliar area consumed by one female and by one male, and the observed sex ratio (0.73), the foliage consumption per beetle was 2.33 cm^2 in 48 h. Adult beetles are present in large numbers for 2–3 mo (dos Anjos *et al.* in press). Given the mean leaf area (3263 cm^2) on the upper crown, and assuming no tree growth and no change in the average number of beetles per tree, the relationships between cumulative foliage

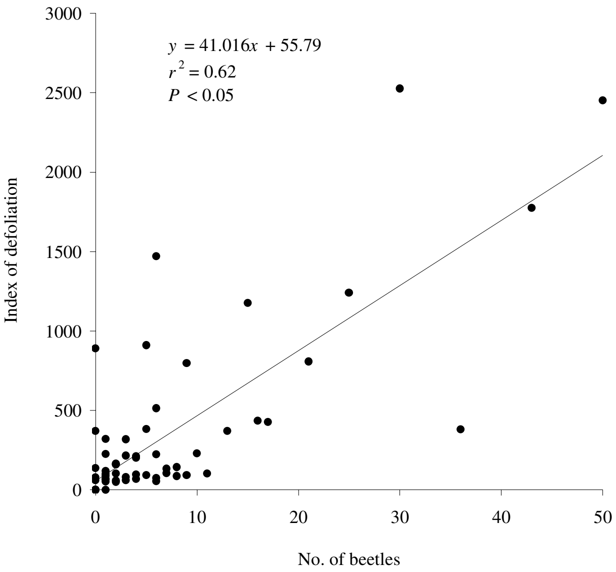

Figure 3. Linear regression of index of defoliation (defoliation level × tree height × tree diameter) for the upper crown versus numbers of *Cadmus excrementarius* beetles in the upper crown of a 9-mo-old *Eucalyptus globulus* subsp. *globulus* plantation

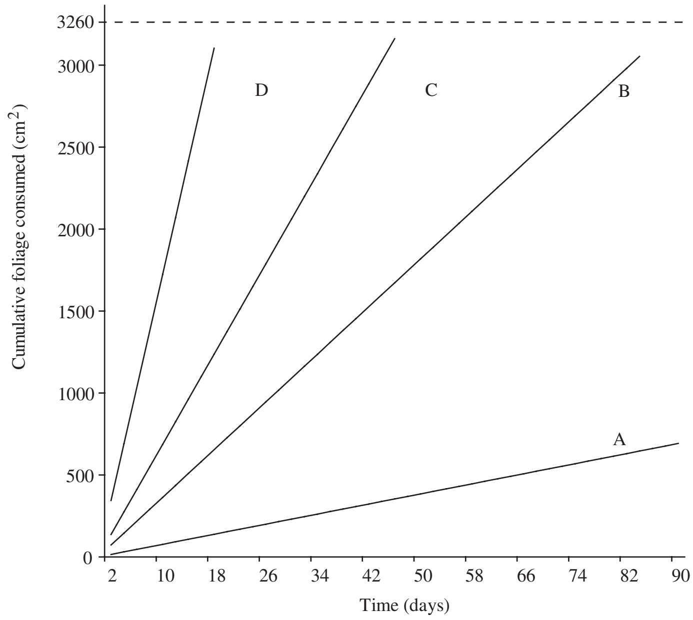

Figure 4. Model of the relationship between cumulative foliage consumption and different numbers (A = 6.6; B = 31.2; C = 59; D = 148) of *Cadmus excrementarius* beetles per average-sized 9-mo-old *Eucalyptus globulus* subsp. *globulus* tree. The broken line indicates the mean area of foliage in the upper crown of a tree of this age.

consumed and different numbers of beetles per tree for different beetle densities can be estimated (Fig. 4). The observed mean field density in this trial (6.6 beetles per tree) was not enough to cause total defoliation of the upper crown over a 3-mo period of regular occurrence (Fig. 4, line A). However, the maximum number of beetles that were observed per tree (59) could cause 100% defoliation to the upper crown within a 48-day period (Fig. 4, line C). Thirty-one beetles per tree (Fig. 4, line B) could also defoliate the upper crown of an average-sized tree within the normal 90-day feeding period, although lower densities would not.

Discussion

Cadmus excrementarius adults were found to have an aggregated spatial distribution at both the plantation and individual tree scale. At the plantation scale, adult distribution appears largely dependent on tree size, with larger trees supporting significantly greater numbers of adult beetles (Fig. 1). Large trees offer more food resources than smaller trees (Landsberg and Hingston 1996), especially in terms of growing shoots, which are preferentially attacked by *C. excrementarius*. Tree size may also reflect specific within-site influences, such as variation in tree fitness as a result of phenotypic heterogeneity. Levels of nitrogen are also known to be associated with insect population densities (Myers and Post 1981; Ohmart *et al.* 1987), so patchy distribution of the fertiliser that was broadcast during plantation establishment could also explain the aggregated distribution of beetles.

At the individual tree scale, there were significantly more adult beetles in the upper crown than in the lower crown. The adults' preference for the upper crown could be explained by the presence of more suitable foliage, as is the case for *Paropsis* leaf beetles (Ohmart 1991), or preference for leaves of particular age classes, a phenomenon that is known for other chrysomelid species (Raymond 1995; Greaves 1966). However, the significant correlation of beetle numbers with the extent of damage on both upper (Fig. 3) and lower crowns highlights the tendency of *C. excrementarius* beetles to feed on the whole crown when in large numbers per tree.

The significant correlation of damage with tree size reflects the numbers of beetles in the tree crown. Similar relationships have been observed by Greaves (1966) on *Eucalyptus regnans* trees attacked by both adults and larvae of *Chrysophtharta bimaculata*. In contrast, Clarke *et al.* (1997) found a different pattern in this leaf beetle, because damage was mainly caused by the larval stage. However, only adults of *C. excrementarius* are able to damage crown foliage, since larvae live on the ground (Loch and Floyd 2001; dos Anjos *et al.* in press).

The population of *C. excrementarius* that we studied was significantly female-biased. Preponderance of females over males has also been observed in *Paropsis atomaria* populations (Carne 1966), but it is not universal amongst chrysomelid beetles (de Little 1983). Further studies on the biology of Cryptocephalinae are required to understand the importance of sex ratios in beetles such as these. Relative to males, females eat far more food than can be attributed to their greater body size. An additional factor would be their necessity to produce eggs (Edwards and Wightman 1984).

Some trees had as much as 50% of the upper crown defoliated, indicating that *C. excrementarius* has the potential to be a serious pest in bluegum plantations. Abbott and Wills (1996) have demonstrated significant effects on blue gum height increment when 50% of the foliage of young trees was manually removed in March. The linear regression of numbers of beetles in the upper crown and the index of defoliation (Fig. 3) suggests that about 148 beetles per tree would be required to cause 100% defoliation to the upper crown of median trees (height = 102 cm, diameter = 1.6 cm) during the annual feeding period. This estimate contrasts with the 31.2 beetles derived from the leaf consumption model (Fig. 4, line B); such a difference could be due to underestimation of the extent of damage when visually evaluating defoliation, and/or to premature evaluation of damage. In the first case, visual evaluation should be calibrated through extensive field data, and in the second case, it is necessary to wait for population decline before assessing defoliation levels. Neither of these procedures was applied when estimating beetle numbers or defoliation levels.

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